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Original Article

Management of Municipal Waste Storage and Transportation Systems Based on Passive Defense Principles: A Case Study in District 6 of Tehran Municipality, Iran

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Abstract

Background: Effective waste management is critical during crises, as it can lead to the release of toxic waste and the mixing of hazardous substances, which can have detrimental effects on the environment and public health. Proper storage and transportation of waste during critical times can significantly reduce vulnerability through the implementation of passive defense measures, as examined in this study.

Methods: This descriptive-analytical research was undertaken to identify passive defense principles and location criteria for waste storage and transportation systems in District 6 of Tehran municipality, Iran. After determining the effective factors in the socioeconomic, physical-spatial, hydrological-climatic, geological, and passive defense sectors, the identified criteria were subdivided into 35 sub-criteria across seven main criteria. These were evaluated by 28 experts in waste management and crisis management using the Delphi method over two stages and subsequently prioritized using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

Results: The criteria "Population density", "Distance to fault", and "Distance to power substation", with similarity to ideal solution (cli) values of 0.861, 0.774, and 0.771, respectively, were identified as the top priorities. Conversely, "Distance to gas pressure-reducing stations" (cli = 0.134) was determined to be the least significant risk factor in the location of the mechanized systems.

Conclusion: Intelligently locating mechanized waste storage and transportation systems based on the coefficients of the prioritized effective factors, following the principles of passive defense, can not only mitigate the vulnerability of the urban area during critical conditions but also enhance environmental and health conditions during normal times.

Keywords: Location criteria, Waste management, Mechanized collection system, Passive defense, Delphi, TOPSIS

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Introduction

Waste management, particularly during natural or unforeseen crises, presents challenges due to technical, equipment, and infrastructure limitations.[1-3] Improper waste management can have detrimental impacts on both the environment and human health,[4,5] contributing to pollution through the release of toxic substances and greenhouse gas emissions.[6,7] These effects can significantly impact socio-economic and environmental well-being.[8,9] Thus, ensuring proper waste management is essential to mitigate these negative consequences.[10,11]

Based on the typical criteria for determining the location of municipal waste collection and storage sites, several influential factors include the population size, per capita waste generation, waste density, existing infrastructure, and proximity to facilities.[12] "Passive defense" should be regarded as a crucial aspect influencing all stages of establishing municipal waste storage and collection systems. Establishing a reliable facility for waste storage and collection necessitates a comprehensive assessment of various environmental, health, and accessibility factors,[13] alongside a thorough understanding of passive defense requirements. Meeting these criteria involves identifying potential threats, assessing the vulnerability of existing sites, evaluating all relevant indicators and requirements for location selection, and ultimately incorporating passive defense considerations into planning processes.[14]

The study of solid waste collection strategies in small municipalities in developing countries revealed the challenges in solid waste management due to factors such as resource constraints and weak institutional capacity of municipalities to adapt to existing waste management structures. Additionally, there are inadequate facilities for collecting, transporting, and disposing of waste, coupled with a low level of public awareness.[15,16] Furthermore, an investigation into the environmental management of urban waste transfer stations in Darabad (Tehran, Iran) indicated that pollution levels in various areas of the station exceeded the standard thresholds.[17]

In a study utilizing geographic information system (GIS) to optimize travel distances, routes, and waste collection time, the results led to the maximization of total waste collection and substantial cost savings. This enabled the determination of the most efficient waste collection routes, vehicle fleet, and capacity for waste collection by the Kampala Capital City Authority.[18] Similarly, to optimize the allocation of spatial areas for urban waste collection using GIS, the shortest route in District 6 of Tehran Municipality, Iran, was identified to reduce time, cost, and manpower.[19] Furthermore, in the evaluation and optimization of the collection and transportation system of solid waste management in Zanjan, Iran, GIS applications were employed to design and forecast the optimal route for waste collection and transportation to the landfill.[20]

In terms of passive defense in location, it entails defense through tools and conditions, with proper siting being a fundamental measure for constructing important and vital structures. Hence, wherever feasible, the establishment of critical and sensitive facilities in areas with high vulnerability coefficients should be avoided. Various factors should be examined to address the issues and complexities associated with the appropriate location for the establishment of vital structures. In alignment with policies and strategic decisions in establishing and expanding facilities and structures, attention should be given to various geographical, social, environmental, cultural, military, etc, factors. Therefore, proper siting and consideration of these factors in the establishment and creation of sensitive and strategic structures can significantly mitigate the risk of vulnerability and their associated risks.[21]

Passive defense does not require any type of weapon against the enemy, and in addition to reducing man-made damage and threats, war, etc, in architecture and urban planning, it can also be useful for reducing vulnerability to all kinds of natural hazards.[22] In urban management, passive defense encompasses self-reliant measures utilizing tools and conditions, minimizing the need for human resources. These actions enhance the defensive capability of complexes during crises while reducing their consequences and enabling cost-effective reconstruction of damaged urban areas. Currently, the primary objective of passive defense is to secure infrastructure essential for people, gradually fostering conditions for security. When these measures are institutionalized as part of a plan and aligned with sustainable development principles, many of the created infrastructures inherently promote self-safety.[23] Essentially, passive defense engineering aims to establish the capacity to prevent and respond to threats to units, thereby reducing vulnerability and crisis consequences.[24]

The Delphi method is primarily employed to scientifically identify the influencing factors in processes such as designing and evaluating the establishment of infrastructure facilities.[25] It entails a group communication process overseen by a supervisory group and conducted in multiple stages by a panel of experts who remain anonymous to each other. Following each stage, the results are disseminated to the participating members of the group.[26]

One of the most common management and planning methods involves employing techniques aimed at achieving the optimal solution. Among these techniques, multiple indicator models, including multi-criteria decision-making (MCDM) methods, are frequently utilized. Various MCDM methods exist, such as the analytic hierarchy process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and the simple additive weighting (SAW) method.

Among these methods, TOPSIS can facilitate decision-making for managers dealing with municipal waste management during crises. Accordingly, the current study employed an integrated approach combining Delphi, TOPSIS, and failure mode and effects analysis (FMEA) to identify and prioritize criteria based on their significance and level of risk.

TOPSIS is a compensatory model within the group of compromise methods, where the option closest to the ideal solution is preferred. This method considers the trade-off between criteria, meaning that weaknesses in one criterion can be balanced by strengths in another. It is a robust MCDM technique used to rank alternatives by comparing them to an ideal solution. TOPSIS enables the comparison of different solutions, selection of the best solution, determination of distances between solutions, and grouping of alternatives. One of its advantages is its ability to handle criteria with diverse units of measurement and both positive and negative natures. This method accommodates a combination of negative and positive indicators for comparison.[27] The evolution of defense strategies and crisis management in cities, influenced by complex natural and man-made hazards as well as advancements in weaponry, has posed challenges for urban planners. Prioritizing urban management and establishing essential urban service facilities can enhance safety, health, and environmental factors, ultimately reducing damages. Hence, this study aims to identify suitable locations for urban waste storage and collection systems in District 6 of Tehran municipality, Iran. The Delphi technique is used to select the most relevant criteria, and the TOPSIS method is applied to weigh these criteria.

Materials and Methods

The study, conducted in 2022 in District 6 of Tehran municipality, Iran, had a descriptive and quantitative survey approach. The research involved 28 experts specializing in waste and crisis management. Sampling was non-random and judgmental, based on the researcher's specific judgment and research objectives. Initially, passive defense criteria and key factors influencing the location of urban waste collection and storage systems were identified. Subsequently, these criteria were refined through a criteria identification matrix and the Delphi method in two stages. The most crucial criteria were then prioritized using the TOPSIS method with input from the expert panel.

Delphi Method

In the initial round, a panel of 28 experts was assembled, comprising university experts in urban waste management and crisis management (Table 1).

The criteria for locating mechanized waste management systems were identified through field surveys, literature reviews, interviews with university professors, examination of study reports, discussions with employees from relevant organizations, completion of relevant checklists, and review of documents and reports from universities and related authorities. A Delphi questionnaire was distributed to the experts to assess the relevance of the identified primary factors to the research topic and to rank their significance using the linguistic variables presented in Table 2. The experts were also encouraged to suggest additional criteria not listed.

In the second round, the expert panel reviewed the designed model based on their feedback from the first round. Subsequently, in the third round, after analyzing the results and making necessary adjustments, the finalized main and sub-criteria were presented to the experts for further evaluation. Following the third round, and upon analyzing the data, the Delphi study concluded as there was no significant change in the dispersion index of the coefficient compared to the second round (change > 20%). For this study, an average score of four or higher was set as the acceptance criterion for each component and variable.[28]

Prioritization of the Criteria by the TOPSIS Method

TOPSIS is among the premier MCDM methods, widely recognized for its diverse applications. The fundamental principle of this technique is that the chosen solution should be closest to the positive ideal solution (A+: representing the best possible scenario) and farthest from the negative ideal solution (A-: representing the worst possible state). It is assumed that the ideality of each criterion either uniformly increases or decreases. Given the significance of the criteria identified in the Delphi method and their varying impact on the municipal waste storage and collection system, it is crucial to assign weights to these criteria relative to each other. The more pivotal criteria should carry greater significance. In this study, the selected criteria were ranked using the TOPSIS method, coupled with an aggregation of expert opinions collected through questionnaires. In this approach, m solutions are assessed based on n criteria. The initial weighting was conducted using the TOPSIS method in seven steps as outlined.[25]

First step: Obtaining the decision matrix that contains *m* solutions and *n* indicators (equation 1).

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ \cdot \\ A_i \\ \cdot \\ \cdot \\ \cdot \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccccccc} x_1 & x_2 & & & & x_j & & & & x_n \end{array} \\ \left[\begin{array}{cccccccccc} x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1j} & \cdot & \cdot & \cdot & x_{1n} \\ x_{21} & x_{22} & \cdot & \cdot & \cdot & x_{2j} & \cdot & \cdot & \cdot & x_{2n} \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ x_{i1} & x_{i2} & \cdot & \cdot & \cdot & x_{ij} & \cdot & \cdot & \cdot & x_{in} \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ \cdot & \cdot & & & & \cdot & & & & \cdot \\ x_{m1} & x_{m2} & \cdot & \cdot & \cdot & x_{mj} & \cdot & \cdot & \cdot & x_{mn} \end{array} \right] \end{array} \qquad (1)$$

where, A_i is the i[th] solution and X_{ij} is the numerical value obtained from the i[th] solution with the j[th] indicator.

Second step: Normalizing the decision matrix; To make the scales in the decision matrix dimensionless, the matrix is normalized. Each value in the matrix is divided by the magnitude of the vector corresponding to the same criterion, ensuring the total weight of the criteria sums up to one. The normalized value r_{ij} for each item is calculated using the equation 2:

$$r_{ij} = \frac{ij}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad (2)$$

Third step: Weighting the Normalized Matrix; the

Table 1. Specifications of the Expert Group

Expert	Frequency	Educational Level	Work Experience (y)
University professors	6	PhD	
Officials and experts of the municipality	13	Bachelor's degree to PhD	13-20
Officials of the waste management organization	5	Bachelor's degree to PhD	21-23
Officials and experts of crisis management organization	2	Bachelor's degree to PhD	20, 28
Officials and experts of the environment protection organization	3	Bachelor's degree to PhD	22-28

Table 2. Linguistic Expressions Used in the Delphi Method and Their Range of Significance Based on the Likert Scale

Linguistic Expressions	Quantitative Value
Very low	1
Low	2
Medium	3
High	4
Very high	5

decision matrix essentially serves as an indicator that requires quantification. The decision-maker assigns a weight to each criterion. The total weights (w) are then multiplied by the normalized matrix (R) (equation 3).

$$W = \left(W_1, W_2, \ldots, W_j, \ldots, W_n\right) \qquad \sum_{j=1}^{n} W_j = 1 \tag{3}$$

Considering that the $W_{n\times 1}$ matrix cannot be multiplied by the normalized decision matrix ($_{n\times n}$), before the multiplication, the weight matrix must be converted into a $W_{n\times n}$ diagonal matrix (weights on the main diameter).

Fourth step: Determining the ideal positive solution (A^+) and the ideal negative solution (A^-), two virtual solutions are defined in equations 4 and 5:

Positive Ideal Solution

$$A^* = \{(max_i v_{ij} \left| j \in J) \& (min_i v_{ij} \right| j \in J') \left| i \right\} = \left\{v_1^*, v_2^*, \ldots, v_j^*, \ldots v_n^*\right\} \tag{4}$$

Negative Ideal Solution

$$A^- = \{(min_i v_{ij} \left| j \in J) \& (max_i v_{ij} \right| j \in J') \left| i \right\} = \left\{v_1^-, v_2^-, \ldots, v_j^-, \ldots v_n^-\right\} \tag{5}$$

The two virtual solutions created are actually the worst and best solutions.

Fifth step: obtaining the size of the distances; the distance between each n-dimensional Euclidean norm solution is calculated. The distance of the i^{th} solution to the positive and negative ideal solutions is calculated by equations 6 ,7 and 8:

$$S_{i*} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2} \; i = 1,2,3,\ldots,m \tag{6}$$

$$S_{i-} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2} \; i = 1,2,3,\ldots,m \tag{7}$$

$$C_{i*} = \frac{S_{i-}}{S_{i*} + S_{i-}} \qquad 0 < C_{i*} < 1 \tag{8}$$

Sixth step: calculating the relative similarity to the idea solution; this criterion is obtained through the equation 9:

$$C_{i*} = \frac{S_{i-}}{S_{i*} + S_{i-}} \tag{9}$$

It is observed that if $A_i = A^+$, then $C_{i*} = 1$; and if $A_i = A^-$, then $C^{i*} = 0$. It is clear that the smaller the distance of the solution Ai from the ideal solution, the closer the relative similarity will be to one.

Seventh step: Ranking the solutions; based on the descending order of C_i, the existing solutions can be ranked based on the greatest significance. the closer the value of C_i is to one, the better the solution.

Results and Discussion

Introducing the Criteria for Locating Municipal Waste Storage and Collection Systems

In today's advanced and modern management landscape, decision-making in complex environments with diverse and numerous (quantitative and qualitative) solutions and criteria is a critical challenge. Decision-makers often encounter various solutions that require prioritization based on a range of criteria, considering both internal and external factors. In this study, multiple meetings were conducted with experts in waste management and crisis management to determine the criteria for municipal waste storage and collection in District 6 of Tehran Municipality. Ultimately, the criteria outlined in Table 2 were identified as suitable for locating the appropriate sites for waste storage and collection systems.

Passive Defense Criteria

The Continuation of the Operation of That Complex in Crisis Conditions, Reducing the Degree of Crisis Escalation Resulting From Injury

Passive defense encompasses planning and measures that reduce vulnerability, increase stability, and maintain the activity of organizations and institutions against external threats, without the need for weapons (unarmed defense). In other words, passive defense refers to all precautionary measures, excluding the use of weapons, aimed at minimizing damages caused by both natural and man-made disasters. From the perspective of passive defense in waste management, reducing the vulnerability of facilities, taking prompt action in evacuation, preventing the dispersion of waste, and safeguarding health and the environment are among the effective factors.[29] Therefore, the criteria for passive defense assess the adherence to passive defense considerations at municipal waste storage and transportation facilities. Within these criteria, sites are compared based on established factors that influence site selection. In the context of establishing a municipal waste storage system, the passive defense criteria are evaluated based on the following considerations: the continued operation of the facility during crisis conditions, minimizing the escalation of crises resulting from damage, and reinforcement, fortification, and dispersion measures.

Identification of Criteria Through the Delphi Method

The present study identified and prioritized the effective criteria for locating municipal waste collection and storage systems in District 6 of Tehran Municipality. After determining the initial criteria using the Delphi method, the final criteria were established. The results from the Delphi method identified factors influencing the location of mechanized systems in the studied district across seven main criteria: socioeconomic, physical-spatial, hydrological-climatic, geological, and three passive defenses, including dispersion, lifeline, and high-risk facilities, along with 35 sub-criteria (Table 3).

Prioritizing the Criteria Through TOPSIS Method

After identifying the location criteria for waste collection and storage systems in the study area through the Delphi method, the next step was to prioritize the most important criteria using the TOPSIS method. To do this, the relative distance of each solution to the ideal one was calculated and ordered from the largest to the smallest. In this method, the solution with the largest relative distance compared to the others receives the highest rank or priority. Initially, the nature of the indicators in the TOPSIS method must be determined, and in this case, all the indicators have a positive nature. The weights of the indicators and the scores of each criterion were determined based on expert opinions and the specific conditions of the studied district. Figure 1 presents the ranking of effective criteria in the location of municipal waste storage and collection systems in District 6 of Tehran Municipality, focusing on environmental and passive defense factors, as determined by the TOPSIS method.

Prioritizing the location criteria of municipal waste collection and storage systems in the studied district using the TOPSIS method (Table 4) revealed that factors A1 (Population density, where higher density leads to greater humanitarian crisis), A20 (Distance to fault, where greater distance results in less humanitarian crisis), and A24 (Distance to power substation, where greater distance results in less humanitarian crisis) were identified as the highest risk factors with similarity to ideal solution (cli) values of 0.861, 0.774, and 0.771, respectively. Conversely, factor A34 (Distance to gas pressure-reducing stations) was determined to be the least significant risk factor ($cl_i = 0.134$).

Figure 1. Ranking of Effective Criteria in the Location of Municipal Waste Storage and Collection Systems in District 6 of Tehran Municipality, Iran, in Terms of Environment and Passive Defense by the TOPSIS Method

Natural and human hazards are always a threat to human life. In recent decades, despite the scientific advances, these risks still impose heavy costs on human societies.[30] In a study, the evaluation of the effects of earthquake and tsunami on waste management in Palu region showed that the establishment of a disaster waste management system requires the preparation of technical guidelines and standard operating procedures in the field of post-crisis waste management.[31] In a study on disaster waste management following the 2009 L'Aquila earthquake in Italy, the results showed that natural disaster waste management is not just a logistical exercise, but it is an integral part of the crisis recovery process, and more efficient planning in this field should be done.[32] In the assessment of threats to health, safety and the environment of the urban waste management process, it was concluded that the participation of organization managers can have a positive effect on threat management and continuous improvement of the waste management process.[33] Accordingly, in the current research, socioeconomic, physical-spatial, hydrological-climatic, geological criteria, and three passive defenses including dispersion, lifeline and high-risk facilities were identified as the most important influencing factors in locating the municipal waste storage system. One of the investigated criteria was population density as the most important influencing factor in the establishment of the municipal waste collection and storage system in the studied district. In a study on optimizing the allocation of spatial boundaries for municipal waste collection using GIS, the results revealed that the "shortness of the transfer path to the landfill" belonging to the physical-spatial criterion was one of the most important parameters influencing the location of the waste storage and transportation system.[34]

In a study on the evaluation of the safety of the urban space in the city of Semnan (Iran) with an emphasis on passive defense indicators using the AHP and TOPSIS methods, the findings indicated that these methods provided more effective results in making decisions about issues related to passive defense.[35] In the evaluation of disaster waste management strategies after the earthquake, the researchers announced that one of the most important effects of the earthquake was the production of a large amount of waste.[36] Therefore, the disaster waste collection process can be managed using a temporary storage site. Prioritization of effective criteria for locating municipal waste collection and storage system in District 6 of Tehran Municipality using the TOPSIS method showed that population density was one of the most important criteria

Table 3. Effective Criteria Identified Based on the Delphi Method and Their Significance in Locating Mechanized Urban Waste Collection and Storage Systems in District 6 of Tehran Municipality, Iran

Criteria	Sub-criteria	Environmental Risks (Results/Effects)
Socioeconomic	A1- Population density	Uncontrolled construction debris limits access for servicing, recovery and reconstruction in the area during a crisis.
	A2- Distance to lines of communication	In times of crisis, communication lines are crucial city facilities that facilitate the process of providing assistance to citizens.
Physical-spatial	A3- Worn-out texture	Worn-out textures are more vulnerable during times of crisis. The proximity of the waste collection system increases the potential for environmental risks
	A4- Land use	The uncontrolled disposal of hazardous substances in disposal sites poses potential risks to human health across various uses.
	A5- Proximity to high-traffic roads	High-traffic roads are vulnerable during a crisis. The presence of urban waste collection and storage centers near these routes poses a significant risk.
	A6- Density of parks and green spaces	Municipal parks and green spaces, as expansive open areas, play a preventive role during times of crisis, reducing the effects and consequences of risks.
	A7- Distance to health centers	Serious health risks to local populations, including outbreaks of disease and infection
	A8- Distance to the nearest fire station	The risk of fire increases during a crisis, and proximity to the fire station plays an essential role in providing timely assistance.
	A9- Distance to the next trash can	The distance between municipal trash cans in neighborhoods is a criterion for the location of the waste collection system. During times of crisis, a large number of trash cans can exacerbate the severity of the crisis.
	A10- Distance to sensitive military places	Proximity to military and law enforcement centers can lead to short-term and long-term conflicts, which may involve missiles, rockets, and bombs. These conflicts, combined with ground warfare, can result in damage to buildings and infrastructure, the bombing of key strategic facilities, or extensive harm to industrial and residential areas.
	A11- Distance to facilities and infrastructure network (water supply network, power lines, sewage network, telecommunications, etc.)	
	A12- Distance to historical and religious places and monuments in the region	Destruction of valuable places by turning them into dumping sites as a result of moving the dumped wastes during the crisis
	A13- Distance to sensitive areas with special ecosystems	Destruction of valuable lands by turning them into dumping sites, additional costs due to the transfer of dumped waste
Hydrological-climatic	A14- Distance to watercourses and canals	In times of crisis, floods result in the mass displacement of household waste, leading to an accumulation of large volumes of waste. Additionally, the flooding causes the mixing of various types of waste, with many hazardous substances getting combined with household cleaning products and electronic goods. Moreover, flooding can deposit mud, clay, and sand in the affected areas, making access difficult and disrupting services and assistance in the region.
	A15- Wind direction	In times of crisis, the wind disperses the odor and pollutants from urban waste more widely.
	A16- Depth of aqueduct	In times of crisis, waste and their leachate seep into the surrounding aqueducts, causing contamination of groundwater sources.
	A17- Well depth	In times of crisis, waste and their leachate seep into nearby wells and cause contamination of groundwater sources, affecting the supply of safe drinking water.
	A18- Distance to water facilities and tanks	In times of crisis, waste and their leachate seep into water facilities and tanks around urban waste collection and storage centers, causing pollution of urban water resources and affecting the supply of safe drinking water.
	A19- Distance to water and wastewater treatment plant	In times of crisis, waste and their leachate seep into wastewater treatment plants near urban waste collection and storage centers, leading to the contamination of treatment facilities and the spread of pollution within the city.
Geological	A20- Distance to fault	Constructing urban waste collection and storage systems near fault lines during crises like earthquakes can result in the destruction of these centers' equipment and the spread of pollution throughout the city
	A21- Soil type	The type of soil is crucial during crises as it influences the infiltration and dispersion of waste, leachate, and their pollutants.
	A22- Slope	A steep slope can increase the risk of rapid building collapse, landslides, and environmental pollution from urban waste.
	A23- Bedrock type	The type of bedrock is crucial during crises such as earthquakes, landslides, floods, and building collapses, as these events can result in the displacement of large amounts of waste within the city.

Table 3. Continued

Criteria	Sub-criteria	Environmental Risks (Results/Effects)
Passive defense (high-risk facilities)	A24- Distance to power substation	Constructing urban waste collection and storage systems near power substations during crises like earthquakes can lead to the destruction of these centers' equipment and the spread of pollution throughout the city.
	A25- Distance to overhead power lines	Constructing urban waste collection and storage systems near overhead power lines during crises like earthquakes can lead to the destruction of these centers' equipment and the spread of pollution throughout the city.
	A26- Distance to gas installations	Constructing urban waste collection and storage systems near overhead power lines during crises like earthquakes can lead to the destruction of these centers' equipment and the spread of pollution throughout the city.
	A27- Distance to oil and diesel tank stations	The construction of urban waste collection and storage systems in the vicinity of oil and diesel tank stations during crises such as earthquakes causes the destruction of the equipment of these centers and the spread of pollution in the city.
	A28- Distance to gas station	The construction of urban waste collection and storage systems in the vicinity of gas stations and gas pumps during crises such as earthquakes causes the destruction of the equipment of these centers and the spread of pollution in the city.
	A29- Distance to oil tanks and warehouses	he construction of urban waste collection and storage systems near fault lines during crises such as earthquakes can result in the destruction of these centers' equipment, the mixing of oil products with waste, and the spread of pollution throughout the city.
Passive defense (lifeline)	A30- Distance to subway	The construction of urban waste collection and storage systems in the vicinity of subway stations during crises such as earthquakes causes the destruction of the equipment of these centers and the spread of pollution in the city. The construction of urban waste collection and storage systems in the vicinity of urban facilities and infrastructure networks in times of crises such as earthquakes causes the destruction of the equipment of these centers, the interruption of vital city facilities, etc. in the city.
	A31- Distance to telecommunications	The construction of urban waste collection and storage systems near communication and telecommunication facilities during crises such as earthquakes can result in the destruction of these centers' equipment, leading to a lack of access and communication between citizens and aid officials.
	A32- Distance to administrative centers	In times of crisis, there is an inability to provide municipal services, such as waste collection, which can lead to excessive waste disposal and disruptions in the operations of both municipal and external organizations.
	A33- Distance to military centers and barracks	In humanitarian crises such as war, rebellion and internal conflicts of military centers
	A34- Distance to gas pressure-reducing stations	The construction of urban waste collection and storage systems in the vicinity of gas pressure-reducing stations in times of crises such as earthquakes causes the destruction of the equipment of these centers and the spread of pollution in the city.
Passive defense (dispersion)	A35- Proper dispersion in locating waste collection systems	Uncontrolled disposal of construction debris restricts access for servicing, recovery, and reconstruction in the area during a crisis. The accumulation of urban waste, including construction debris, leads to increased waste flow in the area, turning it into a dumping site or facilitating illegal disposal of urban waste.

in the location of waste storage and collection system. Population density was identified as the most important criterion in determining the criteria and sub-criteria involved in municipal waste processing technology.[37] The results of a study confirmed that systematic thinking with MCDM approaches always reduces environmental and health risks.[38-40] The results of TOPSIS ranking in the current research showed that this method can be one of the appropriate approaches for weighting effective criteria in locating, in accordance with the results of other researchers.[25]

Conclusion

One of the most crucial strategies for preventing damage, reducing vulnerabilities, and rebuilding sensitive and strategic centers is the implementation of passive defense measures. This study aimed to identify and prioritize effective criteria for locating the municipal waste storage system using the Delphi and TOPSIS methods in District 6 of Tehran Municipality, Iran. The Delphi method results revealed seven main criteria (socioeconomic, physical-spatial, hydrological-climatic, geological) and three passive defense categories (dispersion, lifeline, and high-risk facilities) with 35 sub-criteria influencing the location of mechanized waste management systems. "Population density", "Distance to fault", and "Distance to power substation" were identified as the top-priority criteria with similarity to ideal solution (cli) values of 0.861, 0.774, and 0.771, respectively. Conversely, "Distance to gas pressure-reducing stations" (cli = 0.134) was recognized as the least significant factor in the location of these systems. Strategically locating mechanized waste storage and transportation systems based on the prioritized coefficients of these effective factors, guided by passive defense principles, can not only mitigate urban vulnerabilities during critical conditions but also

Table 4. Determining the Distance to Positive and Negative Ideal Solutions and Ranking Environmental Criteria in the Location of Municipal Waste Collection and Storage Systems in District 6 of Tehran Municipality, Iran Using the TOPSIS Method

Criteria	d^+	d^-	cl_i	Final Rank
A1	0.101	0.624	0.861	1
A2	0.343	0.357	0.510	7
A3	0.432	0.313	0.420	10
A4	0.429	0.277	0.392	13
A5	0.204	0.480	0.702	4
A6	0.549	0.183	0.250	24
A7	0.488	0.221	0.312	20
A8	0.410	0.293	0.417	11
A9	0.455	0.312	0.413	12
A10	0.367	0.330	0.474	9
A11	0.490	0.229	0.319	19
A12	0.541	0.269	0.332	17
A13	0.561	0.152	0.214	27
A14	0.455	0.252	0.357	14
A15	0.307	0.412	0.573	6
A16	0.563	0.253	0.310	21
A17	0.234	0.455	0.661	5
A18	0.483	0.239	0.331	18
A19	0.591	0.159	0.212	28
A20	0.164	0.561	0.774	2
A21	0.565	0.146	0.205	30
A22	0.574	0.152	0.209	29
A23	0.490	0.270	0.355	15
A24	0.162	0.546	0.771	3
A25	0.393	0.393	0.500	8
A26	0.462	0.245	0.346	16
A27	0.538	0.182	0.252	23
A28	0.634	0.063	0.091	34
A29	0.573	0.146	0.203	32
A30	0.570	0.168	0.228	25
A31	0.611	0.177	0.225	26
A32	0.534	0.187	0.259	22
A33	0.682	0.000	0.000	35
A34	0.610	0.094	0.134	33
A35	0.587	0. 151	0.204	31

enhance environmental and health conditions during normal times. The findings of this study demonstrate that employing the integrated Delphi and TOPSIS methods, as a comprehensive approach based on expert opinions, effectively prioritized the most significant influencing factors in the location of municipal waste storage and collection systems.

Suggestions

- Future studies should consider utilizing MCDM methods, such as the analytic network process, which can analyze the internal relationships between criteria. This is especially important when examining municipal areas with varying environmental and social characteristics. Such an approach would allow for a comparison of the influence of the relationships between the measured criteria and their final weights and rankings with those of the current study.
- Given the non-compliance issues observed with established waste storage tanks in certain roads and localities, it is recommended to optimize collection routing and appropriately locate these tanks based on the waste production capacity of the roads and localities. This can be achieved using the proposed model and the WAGS software.
- Adequate funding should be allocated to implement up-to-date and efficient technologies in the design of the mechanized system for municipal waste collection and maintenance.
- Plans should be developed for the establishment of mechanized systems for source-separated recycling of municipal waste in District 6 of Tehran Municipality, Iran.

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Competing Interests

The authors declare any conflict of interest regarding this research.

Ethical Approval

The authors declare that ethical considerations have been observed in the preparation of the article. Evidence for approval by the local ethics committee is provided by the authors upon request.

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